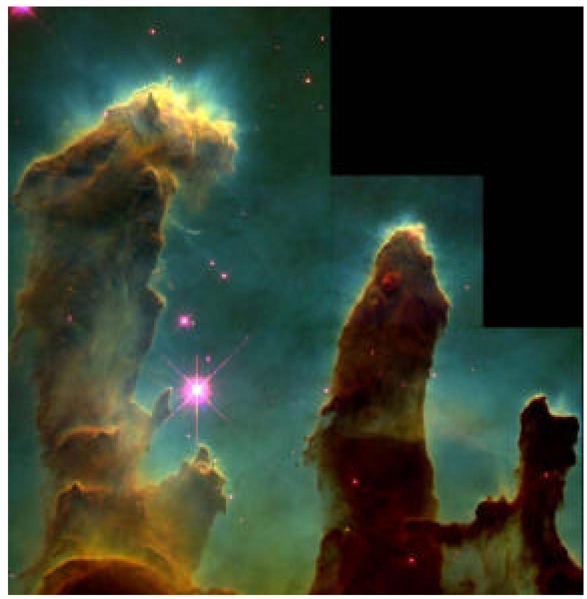
APPENDIX

Formation of a Solar System

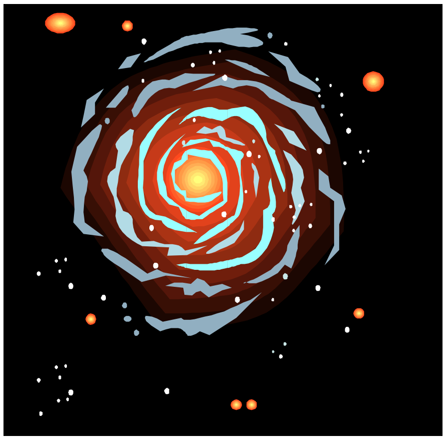
Now that we know that planets do exist around other stars, we can begin to understand a little more about how they form. The fact that we have detected planets around other stars implies that planet formation is a natural by-product of star formation. This is what astronomers have suspected for years. So what do we know about solar system formation?

Astronomers believe that the planets formed at the same time as the Sun, about 4.6 billion years ago, as a giant cloud of interstellar gas and dust contracted. Most of the material fell into the centre of the cloud, becoming the sun, but (to simplify a complicated story) some was left behind in a disk of material circling around the young star. Over time, small grains of dust in the disk collided and stuck together. As they grew larger, their gravity pulled near-by material toward them, increasing their size even more. Eventually they became large chunks, which collided and merged together, until planet-sized objects existed. The planets then swept up the remaining material, pulling the leftover gas and dust toward them, leaving the space between the planets largely empty.



Gaseous Pillars in M16 - Eagle Nebula

This scenario for the formation of the planets helps explain observed similarities between them. All the planets revolve around the Sun in the same direction (counterclockwise as seen from above the north pole of the Sun), and with the exception of Venus and Uranus, all rotate on their axis in a counterclockwise direction. In addition, all the planets circle the Sun in very nearly the same plane. All this can be explained because the planets formed out of the same rotating disk.


An accretion disk viewed from above?

This scenario can also explain their differences, primarily why the terrestrial planets are small and rocky, while the Jovian ones are gassy giants. In the inner part of the solar system, heat from the Sun made it too hot for most of the gas in the disk to condense into a solid. Only small amounts of high-density materials like rock and metals could condense, resulting in small, rocky planets. Farther out in the disk, temperatures were cool enough that a lot of **gassy ice** formed. Thus the outer planets grew quickly, enabling them to become quite big. When they got sufficiently large, they pulled vast amounts of gases like hydrogen and helium toward them, providing the extensive gaseous atmospheres in these planets. The terrestrial planets never got large enough, and the temperature in the inner parts of the disk was too high, to trap the same gases.

If we can't see it how we know it's there?

Astronomers have known for years that seeing a planet around another star would be virtually impossible. This is because; First planets are extremely tiny compared to the stars around which they orbit. Second, seeing planets outside of our own solar system is prohibitive because of the stars around which the planets orbit. Since the stars are so much brighter than the planets themselves (planets do not emit their own light, they just reflect the light of their parent stars), the star's light drowns out any reflected light that might be coming from any planet. These factors conspire to make seeing a planet with a telescope virtually impossible (given current technology) **— planets around other stars are simply too small and too faint to see directly.**

In recent years, however, astronomers have finally reported that they've detected planets orbiting around other stars. Astronomers use the term detected intentionally, because they still have not actually seen a planet (except for a very recent Hubble Space Telescope photo that seems to show what might be a large planet near a star). Instead, astronomers have deduced that planets are orbiting other stars by examining the light and motions of the stars.

HST Photo of a possible planet orbiting a star.

We generally think that the planets in our solar system orbit around the sun, rotating on a point in the centre of the sun. But this is not entirely true. Instead of planets orbiting around the centre of a star itself, both the star and any planets orbiting it, rotate around a neutral pivot point called the Centre of Gravity (see Figure A). This pivot point is not at the centre of the star, but typically near the outer reaches of the star. As a result, the star itself effectively wobbles around this pivot point as it spins, and as its planets orbit.

Figure A

Figure B

To explain this more clearly, an
analogous effect is seen in the athletic event called the Hammer-throw. If you watch a hammer-thrower spin around, you'll notice that they are not standing perfectly upright as they spin, but rather, on an angle. Looking closely, you would notice that the person and the ball actually seem to pivot about a point that is away from the hammer-thrower's body. Figure B. If the ball and its cable were invisible, all you would see is the athlete wobbling back and forth as they spin around.

This wobble is what astronomers have detected in some nearby stars. Astronomers can't see the planets, but they can infer their existence from the wobble of the stars (A lone star with no planets would not be seen to wobble). They do this by first estimating the mass of the star by looking at its light (it's spectrum and colour). Then they determine how much mass there must be orbiting around the star to create the amount of wobble that is detected. In the case of our athlete, if you knew the athletes mass, and their period of wobble back and forth, then you could deduce the mass of the ball that the hammer-thrower was using.

This indirect means of discovering planets has finally revealed that our solar system is not the only one in the Universe.

GLOSSARY

Asteroid -- A rocky space object that can be from a few hundred meters to several kilometres wide. Most asteroids orbit the Sun between Mars and Jupiter.

Cassini -- The name of the planetary probe that NASA is sending to Saturn. It was launched in 1997 and will arrive at Saturn in 2004

Coma -- The cloud of gas and dust surrounding the nucleus of a comet as it approaches the Sun.

Comet -- A small object made of solid ice and dust that travels around the Sun with a very elongated orbit. Comets average about one kilometre in diameter. They are believed to be leftovers from the formation of the solar system. When a comet nears the sun, the light from the sun heats up the comet’s ice and it begins to melt. The melting creates a fuzzy cloud of gas and dust that surrounds the comet (the Coma). The tails of a comet are blown away from the comet by solar radiation.

Gravitational Field (Gravity) -- The force of attraction between two objects, which is influenced by the mass of the two objects and the distances between them.

Jovian -- The term given to objects (moons, asteroids, etc.) that are associated with the planet Jupiter.

Mars Global Surveyor -- A probe currently orbiting Mars. It is being used to examine the early history, geology, and climate of Mars, and to map the Red planet in greater detail than ever before. As the name implies, the probe is surveying Mars topography, magnetism, mineral composition and atmosphere.

By the end of its two year mission, the Surveyor will have sent back more data than all of the other Martian probes combined!

Meteorite -- Fragment of material that falls from space and impacts on other large space bodies.

Solar System -- the Sun and all the planets, comets, asteroids, etc., that revolve around it. Other stars can have solar systems as well. See Appendix Formation of a Solar System for more information.

RESOURCES

WEBSITES

(Begin all addresses with http://)

NASA home page: links to all NASA missions

www.nasa.gov/

NASA Space Link: On-line teachers resources on spaceflight and Aeronautics.

spacelink.msfc.nasa.gov/

NASA education resource pages: Links to teacher resources, activities, glossaries, etc.

education.nasa.gov/

spaceplace.jpl.nasa.gov/

For information on Planetary Exploration see Planetary Science Research Discoveries web magazine

www.soest.hawaii.edu/PSRdiscoveries/

Star Class (Canberra Based)

www.starclass.com.au/

Star Maps for South Eastern Australia

www.assa.org.au/

Hands on activities for planetary science

www.dustbunny.com/afk/

Views of the Solar System

bang.lanl.gov/solarsys/

Jet Propulsion Laboratory “Welcome to the Planets”

pds.jpl.nasa.gov/planets/

Earth and Sky Radio series

earthsky.worldofscience.com/

For information on technology spin-offs from NASA's space program see:

tommy.jsc.nasa.gov/~woodfill/SPACEED/SEHHTML/spinoff.html

Melbourne Planetarium

www.museum.vic.gov.au/planetarium/

The Planetary Society

www.planetary.org

Books and magazine articles for teachers:

- Asimov, Isaac. (1988). Rockets, Probes, and Satellites. Gareth Stevens. (ASIN 1555329616)
- Beatty, J.K., and A. Chaikin, eds (1990). The New Solar System, Third Edition, Sky Publishing Corp., Cambridge. (ISBN 0521645875)
- Christiansen, E.H., and W.K. Hamblin (1995). Exploring the Planets, Second Edition, Prentice-Hall, Englewood Cliffs, New Jersey. (ISBN 0023224215)
- Couper, H and Henbest, N. (1994) How the Universe Works. RD Press. Excellent activities for students on many aspects of astronomy. (ISBN 089577576X)
- Gore, R. Between Fire and Ice: The Planets, in National Geographic, January 1985, p.4.
- Hartmann, W., et al. (1984). Out of the Cradle: Exploring the Frontiers Beyond Earth. Workman. An astronomer and artists showcase space exploration now and in the future. (ISBN 0894807706)
- Henbest, N. (1993). The Planets: A Guided Tour. Viking Penguin. A colourful introduction by a British science writer, with many illustrations. (ISBN 0721456820)
- Levy, D. (1995). Skywatching. RD Press. Beautiful photographic introduction to astronomy (*also available – Advanced Skywatching*) (ISBN 0809493810)
- Miller, R. & Hartmann, W. (1993) The Grand Tour, 2nd ed. Lavishly illustrated travel guide for the solar system, by an artist and an astronomer. (ISBN 1563055112)
- Morrison, D. (1993). Exploring Planetary Worlds. Scientific American Library/W.H. Freeman. The best up-to-date popular level survey of the solar system by an astronomer.
- McNab, D and Younger, J. (1999) The Planets. Book News Inc. Companion book to the acclaimed BBC television series. (ISBN 0300080441)
- Sagan, Carl. (1994). Pale Blue Dot. Random House. Sagan discusses the excitement of planetary exploration and justifications for pursuing our dreams in space. (ISBN 0345376595)

Books for students:

- Azimov, I., & Walz-Chojnacki, G. (1994). Our Planetary System. Gareth Stevens (ISBN 0836811348)
- Azimov, Isaac (1988). Rockets, Probes, and Satellites. Gareth Stevens. (ASIN 1555329616)
- Barnes-Svarney, P. (1993). Travellers Guide to the Solar System. Sterling. Very nice overview of the planets and moons. (ISBN 0806986751)
- Davis, D. & Yeomans, D. (1989). Distant Planets. Facts on File. (ASIN 0816020507)
- Moore, Patrick (1988). Space Travel for the Beginner. Cambridge University Press. A guide to space missions from early rockets through moon and planet probes to the future. (ISBN 0521418356)
- Vogt, G. (1991). Viking and the Mars Landing. Millbrook Press. (ISBN 1878841327)

NOTE: References for individual planets have not been given because of the sheer numbers of publications that exist. For an extensive list of references on individual planets, contact the Tracking Station.